



# Geochemical Characteristics of Metamorphic Rock-Hosted Gold Deposit At Onzon-Kanbani Area, Central Myanmar

Aung Tay Zar<sup>1,3,\*</sup>, I Wayan Warmada<sup>1</sup>, Lucas Donny Setijadji<sup>1</sup>, Koichiro Watanabe<sup>2</sup>

<sup>1</sup>Department of Geological Engineering, Faculty of Engineering, Gadjah Mada University, Yogyakarta, Indonesia

<sup>2</sup>Department of Earth Resources Engineering, Faculty of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan

<sup>3</sup>Department of Geology, Pyaw University, Pyaw, Myanmar

\* Corresponding author : [aungtayzar99@gmail.com](mailto:aungtayzar99@gmail.com)

Tel.: +62-81-329-747-974

Received: June 16, 2017. Revised: July 1, 2017, Accepted: Aug 20, 2017, Published: 1 Sept 2017

DOI : 10.24273/jgeet.2017.2.3.410

## Abstract

Onzon-Kabani area is located on the western border of generally N-S trending Mogoke Metamorphic Belt. Many artisanal and small-scale gold mines were noted since last three decades. Gold mineralization is mainly hosted in marble and occasionally observed in gneiss. Host rocks chemistry is mainly controlled by hydrothermal activities and regional metamorphism. The compatible elements of host rocks are relatively more mobile than incompatible elements during alteration and deformation. Variety of plutonic rocks such as leucogranite, syenite and biotite granite are intruded into older metamorphic rocks. In ACF diagram, leucogranite and syenite are placed in S-type granite field and biotite granite occupied in I-type granite field. Mineralization is observed as fracture filling vein and less amount of disseminated nature in marble unit. Mineralogically, gold is associated with other base metal such as pyrite, galena, sphalerite, and chalcopyrite. Hydrothermal alteration halos are developed as a narrow zone in the peripheral of hydrothermal conduits from proximal to distal; 1) silicic, 2) sericite-illite, and 3) propylitic alteration. In place, silicic altered zone is rich in SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and K<sub>2</sub>O. Moreover, concentrations of S, Cu, Zn, and Pb are more than any other alteration zones. The CaO is gradually increase to least altered zone where wt% of loss of ignition (LOI) also increase significantly to least-altered samples (marble). Some fluid boiling characteristics of vein textures and fluid inclusion petrography are also observed in hydrothermal system of research area. The homogenization temperature (*T<sub>h</sub>*) of quartz vein samples are 159°C to 315°C and salinity are 0.88 to 12.51 wt% of NaCl equivalent. This research focused to describe the geochemical characteristics of metamorphic rock-hosted gold deposit in Onzon-Kanbani area.

**Keywords:** Mogok Metamorphic Belt, Fracture filling vein, Hydrothermal alteration, Fluid boiling

## 1. Introduction

Gold and associated base metal mineralization at Onzon-Kanbani area is located in Thabeikkyin Township, Mandalay region, central Myanmar. This area is west 85km faraway from well known Mogoke Township (ruby land), Myanmar. Small scale local gold rush and abundant artisanal working were started since last thirty years ago. This area is also a part of Mogoke Metamorphic Belt (Searle and Haq, 1964) which famous for their precious and semi-precious gem stones production and distinct geological feature. Mineralization is mostly hosted in marble unit and occasionally in gneiss. It is observed as fracture filling veins and minor disseminated nature in marble. Generally, gold mineralization in Mogoke Metamorphic Belt is inferred as orogenic gold (Mitchell et al., 2004) but locally epithermal and skarn gold mineralization are also spread along this belt (Myint et al., 2014). The main objective of this paper writing is not only to describe the geochemical characteristics of

metamorphic rock-hosted gold deposit but also to understand the deposit genesis of research area.

## 2. Methods of study

Totally, fifty thin and polished sections of altered rocks and ore samples were conducted for mineralogical study by optical microscope and confirmed again by scanning electron microscopy with energy-dispersive X-ray (SEM-EDX). Additionally, X-ray Diffraction (XRD) analysis for the hydrothermal alteration minerals that were done for both bulk rock (random powder) and clay fraction. Major and trace elements analyses were carried out on representative samples using XRF and inductively coupled plasma optical emission spectroscopy (ICP-OES). Moreover, quartz samples were collected from mineralization veins to conduct fluid inclusion study. Double polished quartz wafers were prepared for these quartz veins where the thickness of wafers varied between 150 and 300µm. Microthermometric measurements were done using Linkam THMSG600 combined

heating and freezing stage, attached to Nikon petrographic microscope with Axiovision software. All of these laboratory analyses were made in Department of Earth Resource Engineering, Mineral Resource lab, Kyushu University, Japan.

### 3. Regional geologic setting

Myanmar is tectonically complex region and composed with micro plates such as Sibumasu, West Burma, and India. Along a tectonic history is built by repeatedly occurring subduction, accretion and collision events. These events chiseled the geological landform and metallogenic provinces in Myanmar. Traditionally, the territory of Myanmar is subdivided into (1) the India plate to the west, (2) Burma microplate (West Burma) in the central part and (3) Shan-Thai block (Sibumasu) 'east of the Sagaing fault' (Fig. 1).

Mogok Metamorphic Belt is one of the distinct geological and metallogenic province in Myanmar and located between Central low-land (West Burma) and Shan-Thai block (Sibumasu). It is believed that southern continuation of Himalaya (Searle and Haq, 1964) and formed by either collision (Mitchell, 1979) or strike-slip movement (Metcalf, 2009). In this place, well-known right lateral strike-slip fault, Sagaing Fault (Swe, 1972) is served as a western boundary. Alternatively, the structural configuration of this area is closely related to this fault. Mogok Metamorphic Belt is composed of Paleozoic to Mesozoic meta-carbonate rocks and metapelite where a variety of Cretaceous-Palaeogene plutonic igneous rocks (Barley et al., 2003; Mitchell, 1979; Mitchell et al., 2012) are intruded to older rocks. East of this belt, Shan

Plateau (Sibumasu) is a topographic high with an average elevation of about 1000m and mainly composed of a series of Ordovician-Triassic carbonate rocks and continental sedimentary rocks (Jurassic?). The western margin of Mogok Metamorphic Belt is juxtaposed with Central low-land (West Burma) which is filled by Eocene to Pliocene-Quaternary sediments.

### 4. Geology of Onzon-Kanbani area

Onzon-Kanbani area is a part of Mogok Metamorphic Belt. Therefore, mainly composed with metamorphic and igneous rocks which are exposed with differing areal coverage (Fig. 2). Metamorphic rocks of research area such as a variety of marbles, calc-silicate rocks and gneiss are widely distributed in eastern and western part. The age of the protolith of metasedimentary was originally considered Precambrian (Bender, 1983), but Permian fossils in marble near Kyaukse (Thein and Win, 1969) indicate that Carboniferous to Triassic ages are more likely. Alternatively, igneous units are generally covered the middle part of the research area and found as fitful. The older metamorphic rocks are intruded by granite and syenite. The main igneous intrusion of the research area is biotite granite also called as "Kabaing Granite". The age of magmatism in the Mogoke Metamorphic Belt ranged that magmatism of leucogranite and syenite melt took place in Eocene time during the regional metamorphism and then Kabaing granite intruded the country rocks of the study area in Miocene after regional metamorphism (Barley et al., 2003).

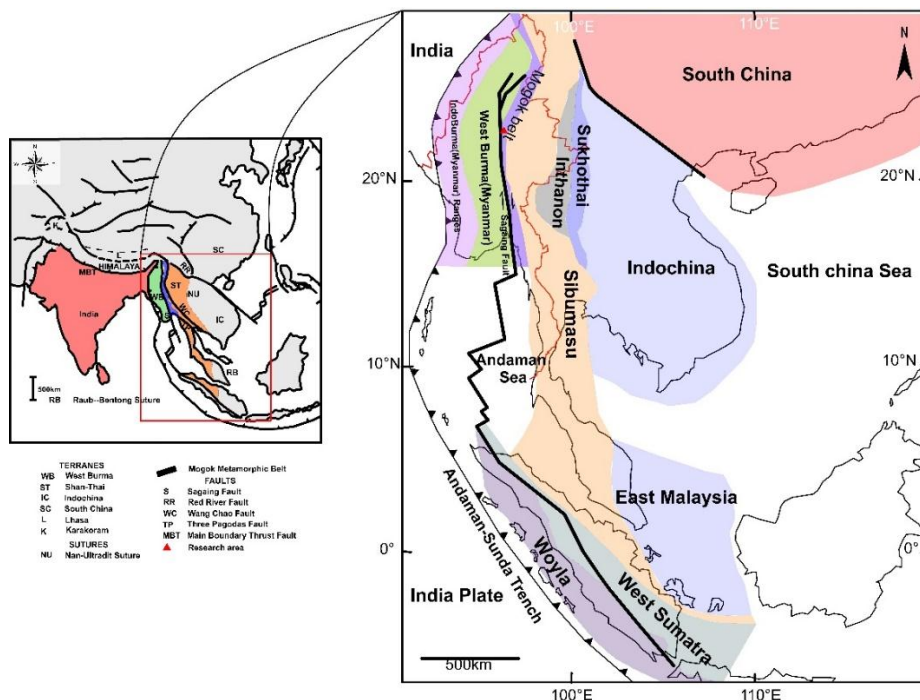


Fig.1. Map showing geologic setting of Mogok Metamorphic Belt and its environ. Modify after (Barley et al., 2003)

## 5. Petrography

The dominant metamorphic rocks in Onzon-Kanbani area which is composed of meta-carbonate rocks (marbles and calc-silicate rock) and biotite gneiss. Heterogeneous igneous intrusions are observed the middle part of the area where diopside calc-silicate rock occur along the margin of igneous intrusions (Fig. 2).

Marble unit appears white (fresh) and dark gray to pale greenish (weathered) in color. The foliated nature also occurs in some marbles (thin foliated marble and diopside marble) and calc-silicate rock. Gneiss unit is medium-crystalline, banded and gneissose with finer and coarser portion. Weathered color light gray and dark gray of fresh surface indicate that abundance of biotite and hornblende in gneiss. In igneous rocks, leucogranite and syenite are observed as small intrusive bodies

intruded to marble units. Light to pinkish color appearance of outcrops are characteristic feature. Biotite granite is a one of important plutonic rock in research area. It has dark grey to yellowish color weathered surface and light grey of fresh surface. The exfoliation nature is common textural feature.

Microscopic observation shows a variety of minerals in marble and gneiss. In marble unit, diopside, phlogopite, calcite are main constituents whereas biotite, plagioclase and quartz are dominant in gneiss. Some of the minerals are believed that the products of regional metamorphism related with India-Asia collision. In syenite and leucogranite, felsic color minerals are mainly observed such as quartz, plagioclase, muscovite and nepheline. The common minerals of biotite granite are quartz, biotite, plagioclase and orthoclase.

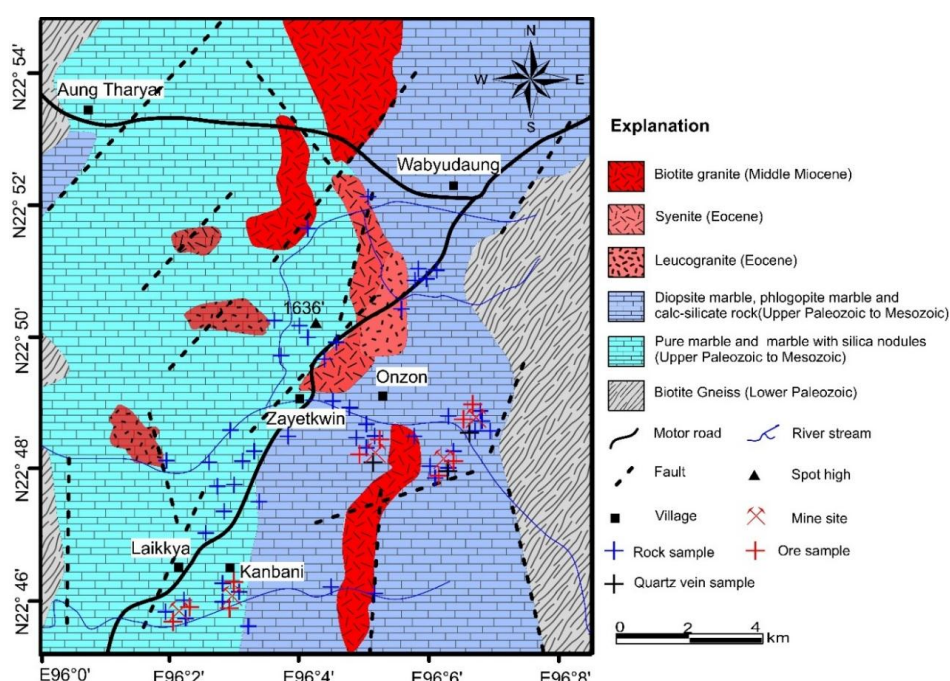


Fig. 2. Simplify geological map of research area with sample location. After Myint Lwin Thein (Thein et al., 1990)

## 6. Petrochemistry

### 6.1 Petrochemistry of host rocks

The major and trace elements composition of host rocks (marble and gneiss) are given in Table-1. The chemical characteristics of host rocks are mainly controlled by regional metamorphism as well as hydrothermal activities. Basically, host rock marble is rich in CaO and MgO whereas the notable amount of  $Al_2O_3$  content showed that their mica content in marble. Alternatively, gneiss samples are a high content of  $SiO_2$  range from 45.983 to 49.672wt% where CaO is not too much between 9.254 to 11.301wt%. In order to evaluate the compositional change which accompanies deformation and hydrothermal alteration, the concentrations of elements of interest are compared to those of immobile such as Zirconium. Typically, Zr is used as an immobile and incompatible element during hydrothermal

alteration due to the very high ionic radius where  $SiO_2$  and some of the major oxide elements cannot use because of alteration effect. In the case of chemically incompatible element Zr versus compatible elements (Zn and Cr) regression lines which are considered to be mobile with each other in the marble and gneiss units during alteration and deformation. The compatible elements (Zn and Cr) are more mobile relative to Zr (incompatible) during deformation and hydrothermal alteration as shown by their poor correlations in Figure (Fig. 3). But in the correlation between both of incompatible elements, Zr vs (Sr and Ba) are considered to be immobile with each other in the marbles and gneiss unit while impacting alteration and deformation. The interelement correlation among the trace elements is significant which is consistent with their similar geochemical behavior.

## 6.2 Petrochemistry of Intrusive Igneous rocks

The chemical composition of plutonic igneous rocks at Onzon-Kanbani area was observed to identify the type of igneous rocks and their tectonic setting. The care during sampling was on fresh rocks, it intended to avoid metasomatic changes during hydrothermal alteration. Results of major and trace elements of plutonic igneous rocks from Onzon-Kabani area are summarized in Table-2. Major element data and converted normative data (CIPW Norm) of plutonic rocks are used to plot on total alkalis-silica (TAS) diagram as well as albite-anorthite-orthoclase triangular diagram to classify these plutonic rocks. According to total alkalis-silica (TAS) discrimination diagram, the plutonic rocks of study area belong to acidic to intermediate rocks of granite and syenite (Fig. 4). The Ab-An-Or discrimination diagram is intended to avoid the

criticism that wt.% oxide data do not faithfully and to confirm plutonic rock classification. This triangular diagram also showed that plutonic rocks of research area are granite, syenite, and tonalite (Fig. 4) respectively. All of these samples are pointed out as calc-alkaline type by AFM diagram (Fig. 4). Moreover, ACF diagram also showed that most plutonic rocks of Onzon-Kabani area are 'S-type' peraluminous except two samples of biotite granite which fall in 'I-type' metaluminous.

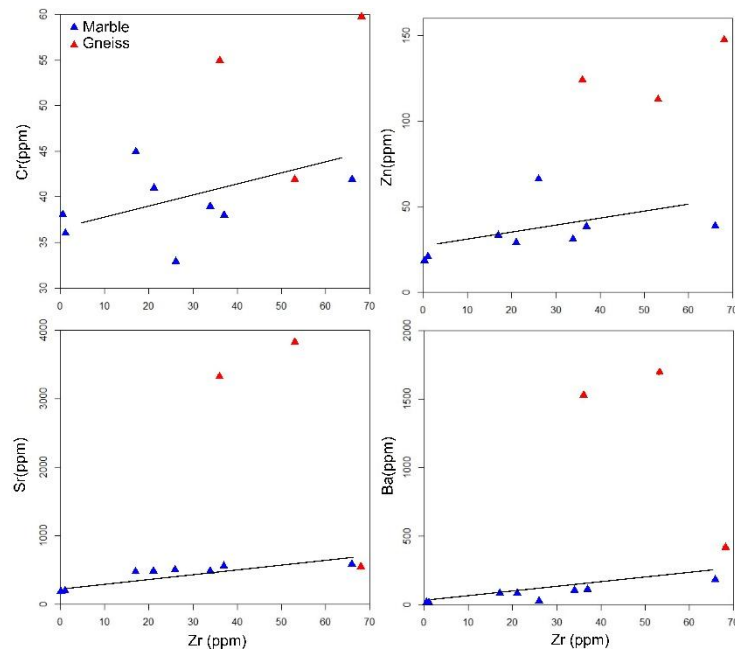
Y versus Nb and Rb versus Y+Nb diagrams (Pearce et al., 1984) were used to discriminate the tectonic environment of plutonic rocks in Onzon-Kanbani area. These diagrams showed that most of plutonic rocks are in syn-collisional granite (syn-COLG) and within plate granite (WPG) except some samples which are placed in volcanic arc granite (VGA) (Fig. 5).

Table 1. Major and trace element composition of least-altered host rocks 'Marble and Gneiss' from Onzon-Kanbani area

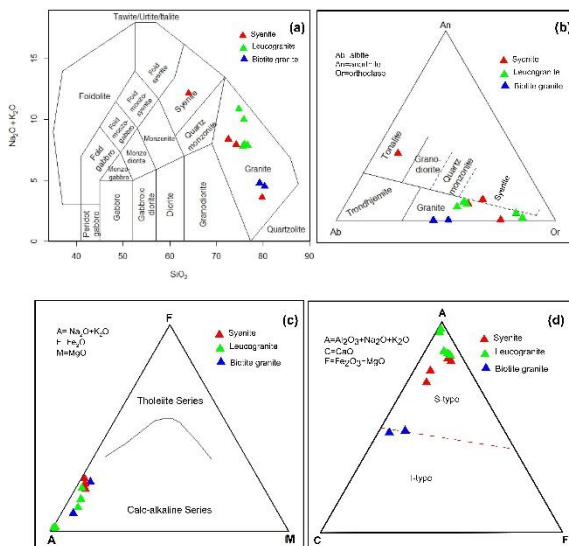
Sample ID	ZYK1 (MB)	ZYK2 (MB)	ZYK3 (MB)	GS (MB)	GS-8 (MB)	GK (MB)	TMA6 (MB)	SZYK3 (MB)	GY-1 (GN)	GY-9 (GN)	ZYK15 (GN)
SiO <sub>2</sub> (%)	2.321	8.123	6.916	5.735	2.259	8.731	10.279	7.786	45.983	49.672	46.304
TiO <sub>2</sub>	0.007	0.166	0.132	0.182	0.009	0.117	0.102	0.194	1.249	1.482	1.385
Al <sub>2</sub> O <sub>3</sub>	0.41	1.912	1.856	1.888	0.36	1.826	1.933	2.449	16.739	15.373	16.274
FeO	0.615	0.697	1.035	0.772	0.607	0.546	1.183	0.727	7.356	8.882	8.238
MnO	0.029	0.031	0.033	0.035	0.037	0.023	0.102	0.03	0.136	0.199	0.173
MgO	6.222	1.982	1.881	1.996	6.626	1.489	2.222	1.765	6.416	7.676	7.029
CaO	48.326	54.134	52.186	52.199	46.124	50.527	48.527	50.583	11.301	9.254	11.088
Na <sub>2</sub> O	0.291	0.005	0.045	0.006	0.383	0.015	0.003	0.063	1.411	1.726	1.669
K <sub>2</sub> O	0.378	0.801	0.59	0.58	0.019	0.861	0.358	0.9	2.317	2.798	2.25
P <sub>2</sub> O <sub>5</sub>	0.003	0.012	0.01	0.011	0.001	0.013	0.006	0.012	0.738	0.224	0.833
LOI	40.01	31.18	34.73	36.42	43.5	35.69	35.12	35.37	3.82	2.13	2.68
Total	98.612	99.043	99.414	99.824	99.925	99.838	99.835	99.879	97.466	99.416	97.923
V(ppm)	5	9	13	22	3	12	15	13	298	334	329
Cr	36	41	39	45	38	42	33	38	42	140	55
Co	11	18	22	24	10	21	23	16	32	33	35
Ni	21	25	24	27	19	22	26	28	48	74	51
Cu	6	8	9	11	5	9	15	7	50	25	47
Zn	21	29	31	33	18	39	66	38	113	148	124
Pb	96	5	7	1	112	n.d	74	7	15	10	1
As	n.d	7	4	7	n.d	10	6	5	13	6	16
Mo	12	15	14	14	9	17	14	17	48	14	41
Sr	181	481	477	473	179	473	495	548	3822	542	3324
Ba	n.d	81	105	84	n.d	180	24	115	1692	425	1532
Y	6	7	11	9	4	10	6	14	20	48	21
Zr	1	21	34	17	n.d	66	26	37	53	68	36
Nb	n.d	2	1	1	n.d	2	1	2	3	13	4
Rb	4	38	30	29	3	36	18	53	57	182	56

Note: Total Fe content expressed as FeO<sub>(tot)</sub>; n.d= below detection limit; major element and LOI are weight percent; trace elements are in ppm

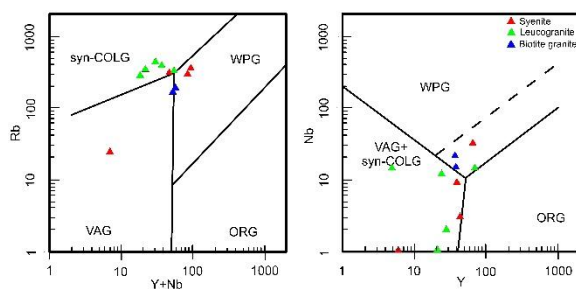




**Fig.3** Binary variation diagrams in Cr, Zn, Sr and Ba (all in ppm) for host rocks of Onzon-Kabani area whereas Zn and Cr are compatible elements, and Zr, Sr and Ba are incompatible elements



**Fig.4.** (a) Classification diagrams of plutonic rocks using total alkaline versus  $\text{SiO}_2$  (Middlemost, 1994), and (b) Ternary plot diagram in normative Ab-An-Or for the plutonic rocks of the study area (O'Connor, 1965), (c) AFM diagram for determining sub-magma type 'tholeiite or calc-alkaline', and (d) ACF diagram determining I-type and S-type granitoid (Hyndman, 1986)



**Fig.5.** Position of Onzon-Kabani plutonic samples on Y versus Nb and Rb versus Y+Nb diagram (Pearce et al., 1984). Abbreviations: ORG=oceanic ridge granite,

VAG=volcanic granite, WPG=within plate granite and syn-COLG=syn-collision granite

## 7. Mineralization and associated hydrothermal alterations

Gold and base metal mineralization hosted by marble is closely associated with intense hydrothermal alteration. Generally, mineralization is controlled by NE-SW trending faults within fracture and shear zones. Open space fracture filling veins are common characteristics with minor disseminated mineralization in marble. Many kinds of vein textures are observed in mineralization vein such as massive vein, crustiform, banded, lattice, bladed carbonate, comb, and cockade. Some of the textures are diagnostic textures of boiling (lattice, bladed, banded, crustiform). They are indicated to boiling fluids of near neutral to alkaline pH condition (Gregg and Jaireth, 1995; Simmons and Christenson, 1994) (Fig. 7). Many local worksites are working on the narrow mineralization zones where the width of veins are generally 0.5 to 5 meters.

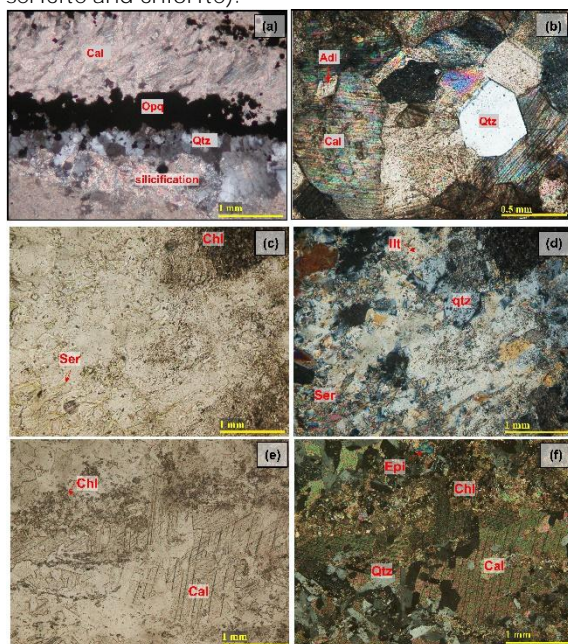
Wall rock alterations related with hydrothermal fluid are observed in Onzon-Kabani area but not wide area scale. Mostly, hydrothermal alteration halos are developed around mineralization veins as narrow zones. Basically, hydrothermal alteration is overlapped to regional metamorphism. Microscopic observation and X-ray diffraction patterns are used to identify the type of alterations which happen by hydrothermal impact. There are three distinct hydrothermal alteration zones from proximal to distal of hydrothermal conduct.

Silicic alteration zone or inner core of alteration halos, it is mainly composed of quartz, calcite, adularia and minor amount of illite and chlorite (Fig.6). Generally, this alteration is overlapped with mineralization vein but groundmass is strongly

silicified. Gold and base metal mineralization are observed in massive and banded quartz veins. Hydrothermal breccia is also frequently observed near this alteration zone. These breccia are characterized by a milled matrix of pyrite. Some of the sulphides are oxidized because of deep weathering.

Sericite-illite alteration is observed as narrow zone next to silicic alteration zone. But this zone is not well developed in some alteration halos. The main constituents of minerals from this altered zone are sericite, illite, quartz, calcite and a minor amount of pyrite. Sericite occurs as fine grained and spread out like dusty (Fig. 6).

Propylitic alteration is an outer most zone of alteration and wide area coverage. This zone is characterized by the presence of chlorite, epidote, actinolite, smectite, and illite, (Fig. 6). It is still preserve the primary texture of the original rock. It is believed that some part of propylitic alteration is not related to ore forming hydrothermal system (Evans, 1987), overlapped to regional metamorphism. Most of hydrothermal minerals from each altered zones showed that near neutral condition of pH (e.g. adularia, calcite, illite, sericite and chlorite).

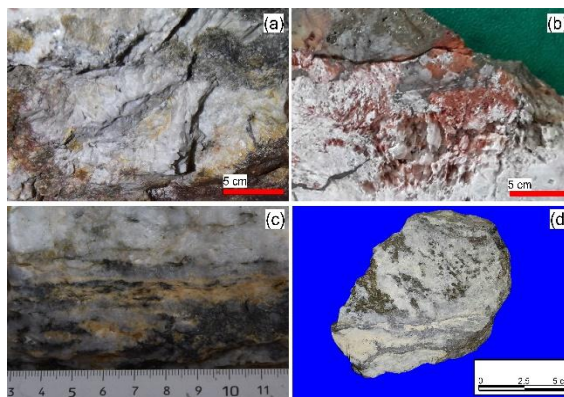


**Fig. 6.** Photomicrographs of (a & b) Silicic alteration, (c & d) Sericite-illite alteration zone, (e & f) Propylitic alteration zone. Abbreviations: calcite (Cal), quartz (Qtz), adularia (Adl), sericite (Ser), illite (Ill), epidote (Epi), chlorite (Chl) and opaque mineral (Opq).

## 8. Geochemistry of altered rocks

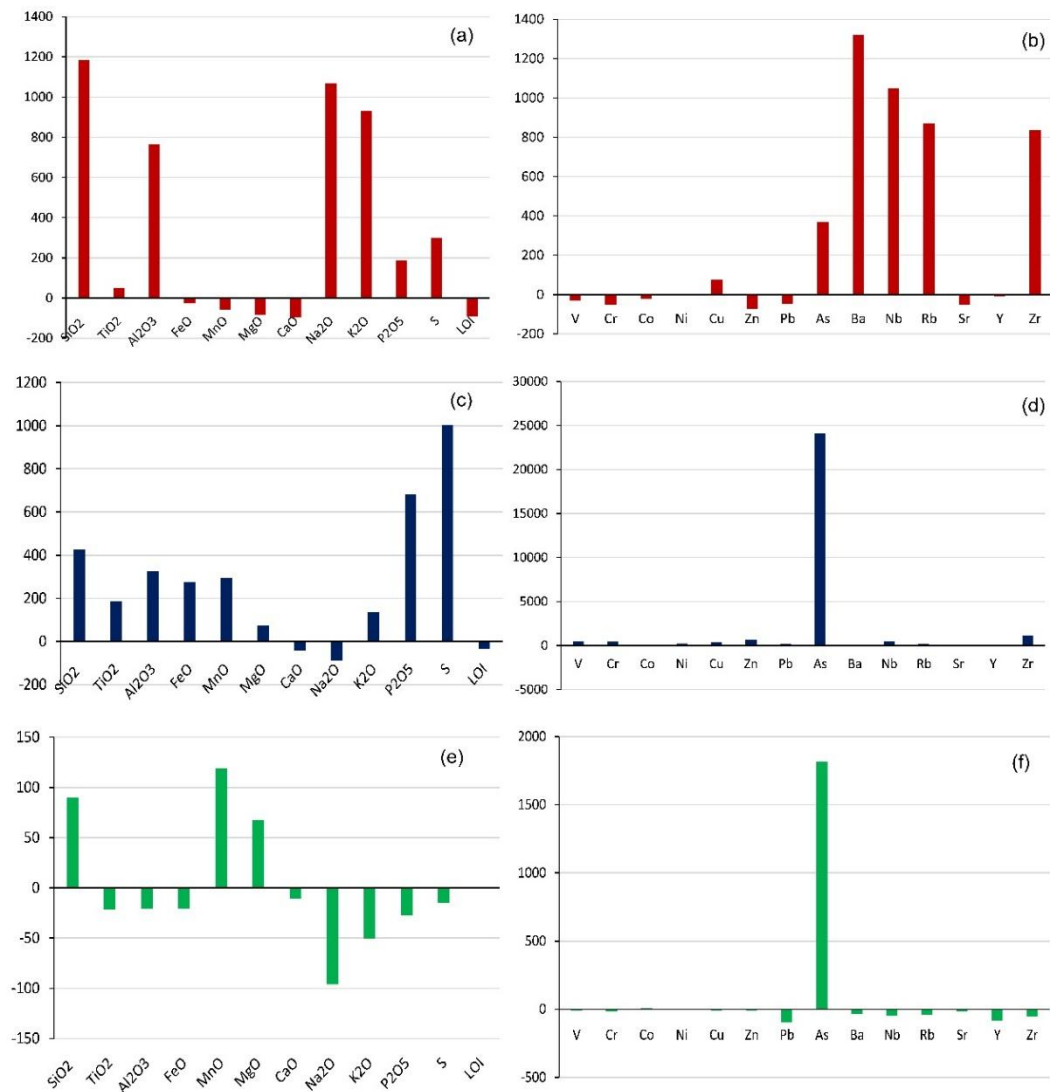
The major and trace elements concentration of the altered rocks are varied depend on alteration intensity as well as the presence of a chemical ion exchange between wall rocks and hydrothermal fluids. The altered zonation reflects changes in the fluid composition with time and interaction of

hydrothermal fluid and wall rocks (Meyer and Hemley, 1967).

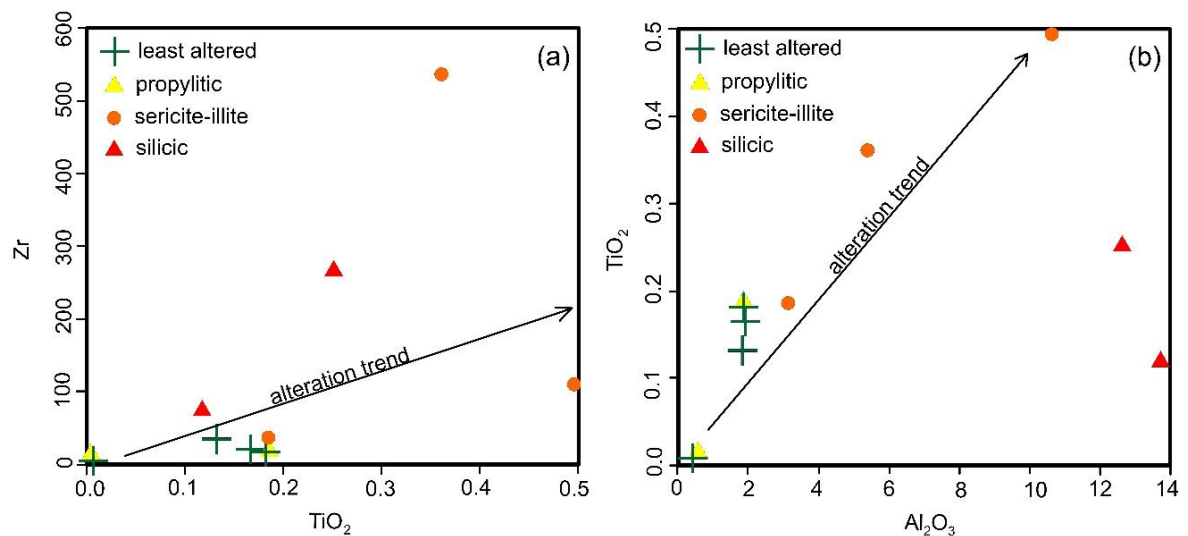


**Fig. 7.** Some of the mineralization vein textures (a) Lattice texture, (b) bladed calcite, (c) banded vein texture and (d) crustiform texture

In Onzon-Kabani area, alteration zones are basically hosted in marble unit as narrow zonation. The major and trace elements of the least-altered rocks and altered rocks of each zones are shown in Table 1 and 3. In this case each of the alteration zones has measured enrichment and depletion of major and trace elements relative to the least-altered rock (Fig. 8). The petrochemistry of zone 1 showed that silicic altered rocks are enriched in  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{K}_2\text{O}$ , and S indicating occurrences of abundant quartz, aluminium-bearing clay (illite),  $\pm$  adularia and sulphides whereas any other elements such as FeO, MgO, MnO and CaO are depleted. But in zone 2 of sericite-illite alteration zone,  $\text{SiO}_2$  is quite reduced compared with silicic alteration zone. Instead of  $\text{SiO}_2$ , CaO is increased in remarkable amount but still low relatively to least-altered rocks. Moreover,  $\text{Al}_2\text{O}_3$ ,  $\text{K}_2\text{O}$ , FeO and MgO are also high because of abundant illite (sericite) and chlorite. **Samples from zone 3 'propylitic alteration zone'**, CaO shows high amount near least-altered rocks whereas  $\text{Al}_2\text{O}_3$  and  $\text{K}_2\text{O}$  are depleted. Locally enrichments of MgO,  $\text{Al}_2\text{O}_3$  and FeO are indicated that the development of chloritization in propylitic alteration. The wt.% of loss of ignition (LOI) increase significantly to least altered samples (marbles). This is due to dissociation of  $\text{CaCO}_3$  and dolomite  $\text{CaMg}(\text{CO}_3)_2$  that partially transform themselves into carbon dioxide gas at temperatures higher than  $750^\circ\text{C}$ . Generally, high field strength elements of Al, Ti, and Zr were assumed to be immobile elements during the alteration and deformation process. When plotting these minerals from least-altered and altered rocks in  $\text{TiO}_2$  vs Zr and  $\text{TiO}_2$  vs  $\text{Al}_2\text{O}_3$  binary/bivariate diagrams, a general single trend of alteration is observed in both of diagrams but some of silicic and sericite-illite alteration samples are a little bit deficient from these lines (Fig. 9). It means hydrothermal alteration of silicic and sericite-illite alteration is quite high intensity.



**Fig.8** Enrichment –depletion diagram showing major oxides (wt%) and trace element (ppm) during alteration in different zones of hydrothermal alteration of Onzon-Kanbani area based on mean data of least-altered samples as a reference for calculations, (a) and (b) for silicic alteration zone, (c) and (d) for sericite-illite alteration zone, and (e) and (f) for propylitic alteration zone



**Fig.9** Binary diagrams Zr-TiO<sub>2</sub> and TiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> showing plot of the least-altered and altered rocks with alteration trend

**Table 2.** Major and trace element composition of plutonic rocks from Onzon-Kanbani area

Sample ID	ZYKI-2 (luc)	ZYKI-3 (luc)	ZYK-5 (luc)	ZYK-9 (syn)	ZYK-11 (syn)	ZYK-12 (Gr)	ZYK-18 (luc)	KB(Gr)	ZYKS-1 (luc)	ZYKS-2 (syn)	ZYKS-3 (luc)
SiO <sub>2</sub> (%)	74.27	75.4	75.49	78.85	73.73	79.77	61.51	79.07	75.63	75.51	71.53
TiO <sub>2</sub>	0.03	0.27	0.03	0.07	0.38	0.26	0.2	0.01	0.05	0.34	0.33
Al <sub>2</sub> O <sub>3</sub>	13.65	12.48	13.09	11.85	12.69	5.09	13.02	5.34	12.38	12.08	13.91
FeO	0.23	2.43	0.21	1.21	3.1	1.73	1.8	0.55	1.77	1.18	2.56
MnO	0.01	0.03	0.02	0.01	0.07	0.05	0.03	0.01	0.01	0.03	0.06
MgO	0.02	0.32	0.05	0.16	0.16	0.29	0.81	0.28	0.47	0.53	0.47
CaO	0.28	0.89	0.57	3.13	1.17	7.52	6.88	9.57	1.08	1.26	1.42
Na <sub>2</sub> O	1.14	2.78	1.2	2.76	2.44	1.15	2.82	2.65	2.42	2.51	1.99
K <sub>2</sub> O	9.68	5.03	8.78	0.78	5.51	2.35	8.86	2.12	5.48	5.25	6.32
P <sub>2</sub> O <sub>5</sub>	0.02	0.02	0.02	0.01	0.04	0.06	0.01	0.01	0.03	0.06	0.01
LOI	0.5	0.22	0.31	0.63	0.48	0.51	3.3	0.32	0.61	1.2	1.12
Total	99.83	99.87	99.77	99.46	99.79	99.78	99.24	99.93	99.23	99.15	99.72
V(ppm)	6	6	5	2	18	14	15	7	21	2	8
Cr	22	24	24	27	20	30	22	20	19	24	23
Co	21	9	10	13	2	7	12	4	2	17	4
Ni	27	26	25	21	28	26	23	24	24	21	23
Cu	3	4	7	8	9	6	50	7	5	7	8
Zn	8	103	4	20	93	51	12	65	63	46	62
Pb	20	27	35	11	25	25	43	28	35	25	21
As	5	8	8	6	10	6	10	9	8	5	9
Mo	12	25	33	14	27	17	16	16	12	18	15
Rb	437	296	336	27	291	165	359	187	281	378	308
Sr	276	35	263	33	56	266	560	267	225	617	596
Ba	644	211	660	11	214	1033	4552	1015	484	1246	1568
Y	29	72	21	6	41	39	66	37	5	25	45
Zr	n.d	473	429	37	731	249	17	14	122	425	476
Nb	2	14	1	1	9	15	32	22	14	12	3

Note: Total Fe content expressed as FeO<sub>(tot)</sub>; n.d= below detection limit; major element and LOI are weight percent; trace elements are in ppm

**Table 3.** Result of XRF and ICP-OES altered host rock from Onzon-Kanbani area, Thabeikkyin Township, Mandalay region, Myanmar

	Silicic Alteration		Sericite alteration			Propylitic		least-altered
	GM-8	GM-9	GK-3	GK-5	CHL1	GS1	GM11	mean (n=4)
SiO <sub>2</sub> (%)	72.507	75.66	38.975	12.556	39.396	5.735	16.169	5.7737
TiO <sub>2</sub>	0.25	0.117	0.497	0.184	0.36	0.182	0.009	0.1217
Al <sub>2</sub> O <sub>3</sub>	12.582	13.649	10.708	3.127	5.428	1.888	0.51	1.5165
FeO	0.796	0.347	5.789	1.003	2.03	0.772	0.469	0.7797
MnO	0.027	0.001	0.202	0.129	0.049	0.035	0.105	0.032
MgO	0.697	0.212	3.242	0.994	11.675	1.996	8.134	3.0202
CaO	2.269	0.703	18.791	45.956	22.449	52.199	39.786	51.7112
Na <sub>2</sub> O	0.137	1.889	0.022	0.001	0.005	0.006	0.001	0.0867
K <sub>2</sub> O	6.521	5.587	3.033	0.609	0.542	0.58	0.003	0.5872
P <sub>2</sub> O <sub>5</sub>	0.032	0.02	0.09	0.022	0.099	0.011	0.002	0.009
S	0.4396	0.0127	1.8	0.0318	0.0377	0.0851	0.0108	0.0564
LOI	3.55	1.62	16.06	35.31	17.82	36.42	34.76	35.585



Total	99.8076	99.8177	99.209	99.9228	99.8907	99.9091	99.9588	99.2232
V(ppm)	11	6	163	17	32	22	n.d	12.25
Cr	18	19	554	34	46	45	24	40.25
Co	8	22	20	n.d	15	24	16	18.75
Ni	24	24	194	24	27	27	19	24.25
Cu	18	12	92	10	9	11	4	8.5
Zn	88	71	535	68	67	33	18	28.5
Pb	89	60	210	14	4	1	n.d	27.25
As	39.33	2.92	3267.87	n.d	n.d	172.26	n.d	4.5
Ba	866	1051	224	49	104	84	5	67.5
Nb	14	9	4	6	8	1	n.d	1
Rb	289	201	120	43	30	29	2	25.25
Sr	124	248	317	367	199	473	199	403
Y	9.32	5.81	17.67	6.43	8.42	n.d	2.78	8.25
Zr	267	75	111	32	537	17	n.d	18.25

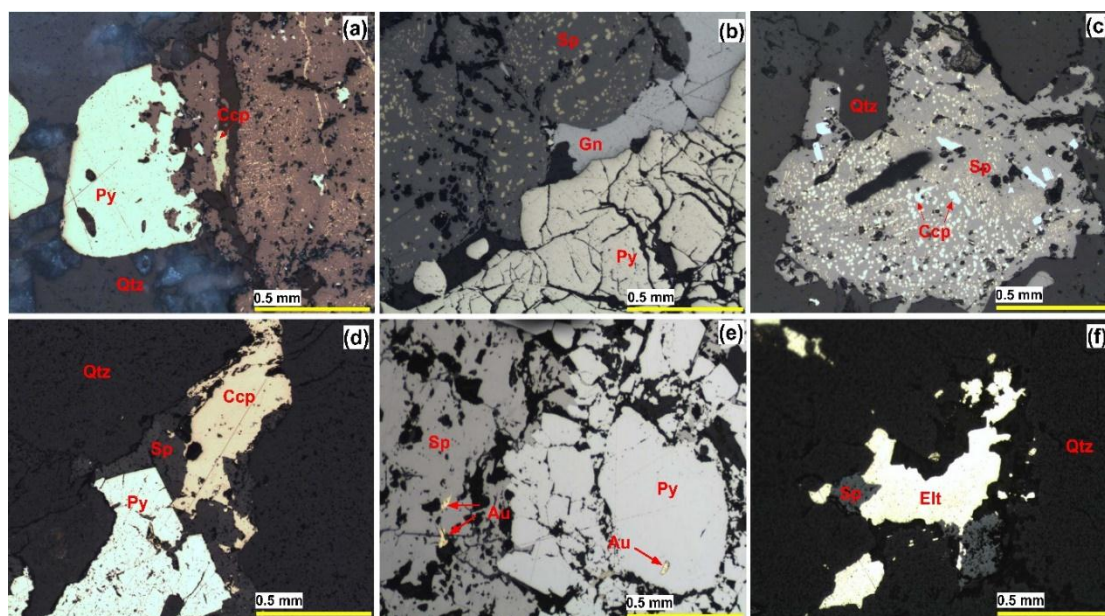


Fig.10 Ore microscopic images of selected samples (Py=pyrite, Gn=galena, Sp=sphalerite, Ccp=chalcopyrite, Au=native gold and Elt=electrum)

## 9. Ore mineralogy and paragenetic sequence

Mineralogically, gold occurs as free grains or locked within pyrite, sphalerite, galena and gangue mineral quartz. There are two types of gold, 'native gold' and 'electrum' based on their atomic percent of Au. Electrum (<80 at %) is mostly observed as large grained in gold bearing quartz vein but native gold (>80 at %) is observed as fine grained in base metal quartz-carbonate vein and carbonate base metal sulphides vein (Fig.11). Other common ore minerals in research area are pyrite, marcasite, chalcopyrite, sphalerite, galena, arsenopyrite, chalcocite, covellite, hematite, and goethite. Pyrite, galena, sphalerite, chalcopyrite, marcasite, and

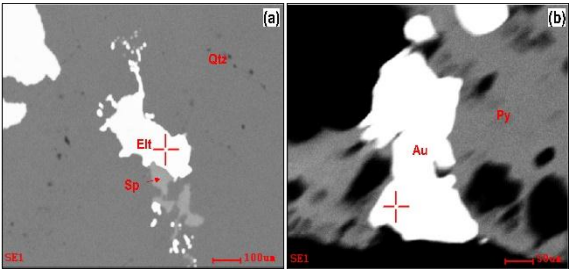
arsenopyrite are primary ore minerals whereas chalcocite, covellite, hematite, and goethite occur as late minerals, their occurrences reflect the oxidation of primary sulphides such as pyrite and chalcopyrite by circulation of surficial water. Pyrite is the most abundant sulphide mineral in the ore body. It occurs over the entire period of mineralization as fine-grained massive aggregates to large euhedral grains.

According to the vein and mineral structures and textures, there are three main paragenetic stages; 1) mineralization stage, 2) barren stage and 3) oxidation stage (Table-4). In mineralization stage, the early formed quartz, pyrite, and minor calcite minerals are observed away from late phase

sulphides and quartz core vein. And also early formed pyrite and quartz minerals showed their euhedral crystal forms whereas anhedral sphalerite is younger than quartz and pyrite in order of deposition. Some of the anhedral sphalerites are replaced along the boundary by later formed galena. Moreover, disseminated chalcopyrite rods and small grains occur in sphalerite as exsolution texture (Fig. 10). Gold is mostly observed in quartz gangue, pyrite, sphalerite, galena and chalcopyrite ground mass as disseminated specks (Fig. 10). Actually, quartz, calcite, and pyrite are observed the entire period of mineralization as more or less amount. Sericite and a minor amount of adularia are also found together with quartz at mineralization vein. After mineralization stage, veins are barren like a calcite or quartz vein with very minor amount of pyrite. Subsequently, oxidation stage is going on by circulated meteoric water whereas hematite, goethite, and chalcocite are formed from primary sulphides.

**Table 4.** Generalized paragenetic sequence of Onzon-Kanbani area

Minerals	Stage-1 (Mineralization)		Stage-2 (Barren)	Oxidation stage
	Phase-1	Phase-2		
Quartz	—	—	—	—
Adularia	—	—	—	—
Sericite	—	—	—	—
Calcite	—	—	—	—
Illite	—	—	—	—
Pyrite	—	—	—	—
Arsenopyrite	—	—	—	—
Sphalerite	—	—	—	—
Galena	—	—	—	—
Chalcopyrite	—	—	—	—
Electrum	—	—	—	—
Native Gold	—	—	—	—
Marcasite	—	—	—	—
Chalcocite	—	—	—	—
Covellite	—	—	—	—
Hematite	—	—	—	—
Goethite	—	—	—	—

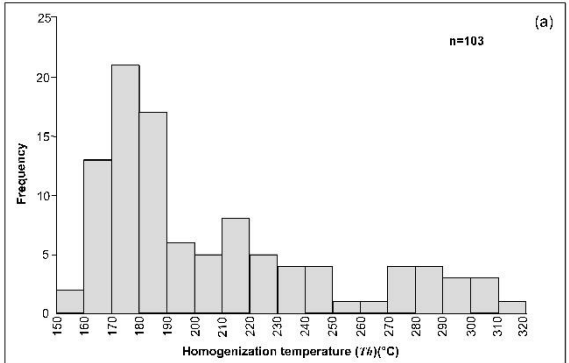


**Fig.11** Back scatter image of electrum gold and native gold in mineralization vein (El=electrum, Au= native gold, Sp=sphalerite, Py=pyrite, Qtz=quartz)

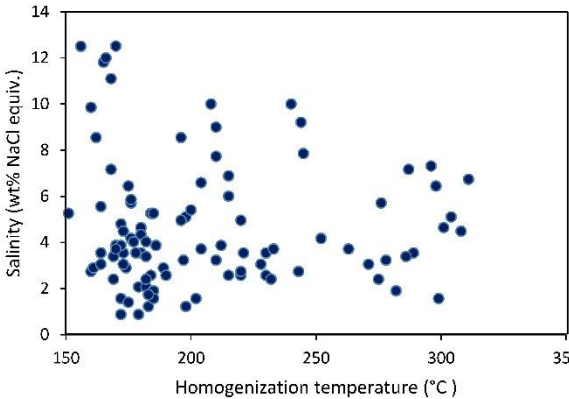
### 10. Fluid inclusion study

Double polished quartz wafers were prepared for fluid inclusion study. From petrographic study, two-phase (liquid, vapor) fluid inclusions are dominant type of primary fluid inclusion. They are observed as two-phase liquid rich, two-phase coexisting of liquid-rich and vapor-rich and two phase vapor-rich fluid inclusions. Moreover,

microthermometry was carried out for primary fluid inclusions in quartz from gold and base metal mineralization veins. Homogenization temperature  $T_h$  of fluid inclusion showed range from 159°C to 315°C where the boiling temperature was estimated to be 170°C. The histogram of homogenization temperature is shown in figure (Fig. 12). Salinities of the fluid inclusions were calculated by Bodnar's equation using ice melting temperature  $T_m$  (Bodnar, 1993). The salinity range is low to moderate 0.88 to 12.51 wt% NaCl equivalent. The plot diagram of homogenization temperature and salinity are showed negative trend (Fig. 13).



**Fig.12** Homogenization temperatures of fluid inclusion in quartz from gold and base metal mineralization vein



**Fig. 13.** Binary plot diagram of salinity vs. homogenization temperature  $T_h$  of fluid inclusions

### 11. Discussion and conclusion

Gold mineralization in Onzon-Kanbani area is hosted in metamorphic rocks. The older metamorphic rocks are intruded by younger plutonic rocks. Mineralization is commonly observed as fracture filling vein and disseminated nature hosted in marble unit. Petrochemistry of host rocks is mainly controlled by regional metamorphism and hydrothermal activities. Basically, host rocks are rich in CaO and MgO whereas the notable amount of  $Al_2O_3$  content is showed their mica content in marble. Both of 'I-type' biotite granite and 'S-type' leucogranite and syenite of granitoid rocks are observed as intrusive bodies where most of the rocks are placed in the field of

syn-collisional granite and within plate granite. Hydrothermal alteration halos are developed as narrow zones beside of hydrothermal conduit or mineralization vein. They are silicic, sericite-illite and propylitic alteration zones from proximal to distal of hydrothermal conduits. Hydrothermal alteration in Onzon-Kanbani area is regarded as low-sulphidation epithermal system as indicated by the characteristic of alteration style and alteration mineral assemblages such as quartz, calcite,  $\pm$ adularia, sericite, illite and smectite. These alteration minerals are showed that the temperature decreasing to the outer zone of alteration as well as indicated that the higher pH, near neutral condition of hydrothermal system. Generally, hydrothermal alteration is overlapped to regional metamorphism. The geochemistry of each altered zone reflects changing of fluid composition and interaction of hydrothermal fluid and wall rock. According to immobile elements characteristics of least-altered and altered rocks, alteration intensity is higher to silicic and sericite-illite alteration.  $\text{SiO}_2$  and CaO content are inversely proportional in each altered zone. Enrichments of S, Pb, Zn, and Cu from silicic altered zone indicate that fracture filling vein mineralization is more common than disseminated mineralization. In ore mineralogy, hypogene ore mineral such as pyrite, sphalerite, galena, chalcopryrite and minor native gold and electrum are precipitated in mineralization stage. After this veins are barren by deposition of calcite or quartz at the end of mineralization stage. Some of hypogenesulphide minerals are oxidized to supergene minerals during oxidation stage. According to fluid inclusions petrography whereas coexisting of liquid rich and vapor rich fluid inclusions as well as some of vein textures such as bladed, banded and lattice are strongly advocated that fluid boiling, is effective on such a precipitation of ore minerals. Moreover, homogenization temperature ( $159^\circ\text{C}$ - $315^\circ\text{C}$ ) and salinity (0.88 to 12.51 wt.% NaCl equiv.) range are acceptable to say it formed in the epithermal environment.

### Acknowledgements

This research is supported by AUN/SEED-Net (JICA program). We would like to thank all of local companies and owners for permission to conduct research work in there and for helping during field investigation and general discussion.

### References

- Barley, M.E., Pickard, A.L., Zaw, K., Rak, P., Doyle, M.G., 2003. Jurassic to Miocene magmatism and metamorphism in the Mogok metamorphic belt and the India-Eurasia collision in Myanmar. *Tectonics* 22, n/a-n/a. doi:10.1029/2002TC001398
- Bender, F., 1983. *Geology of Burma*, 293 p. Gebrüder Borntraeger, Berlin and Stuttgart.
- Bodnar, R.J., 1993. Revised equation and table for determining the freezing point depression of H<sub>2</sub>O, 683–684.
- Evans, A.M., 1987. *An Introduction to Ore Geology*, 2nd edn. ed. Blackwell, Oxford.
- Gregg and Jaireth, S.D.G. and M., 1995. Quartz textures in epithermal veins, Queensland; classification, origin and implication. *Econ. Geol.* 90, 1841–1856.
- Hyndman, D.W., 1986. Petrology of Igneous and Metamorphic Rocks. *Geol. Mag.* 123, 88–89. doi:10.1017/S001675680002673X
- Metcalfe, I., 2009. Late Palaeozoic and Mesozoic tectonic and palaeogeographical evolution of SE Asia. *Geol. Soc. London, Spec. Publ.* 315, 7–23. doi:10.1144/SP315.2
- Meyer, C., Hemley, J.J., 1967. *Geochemistry of hydrothermal ore deposits*. Holt, Rinehart and Winston, New York.
- Middlemost, E.A.K., 1994. Naming materials in the magma/igneous rock system. *Earth-Science Rev.* 37, 215–224. doi:10.1016/0012-8252(94)90029-9
- Mitchell, A.H.G., 1979. Guides to metal provinces in the Central Himalaya collision belt; the value of regional stratigraphic correlations and tectonic analogies. *Mem. Geol. Soc. China* 3, 167–194.
- Mitchell, A.H.G., Ausa, C.A., Deiparine, L., Hlaing, T., Htay, N., Khine, A., 2004. The Modi Taung - Nankwe gold district, Slate belt, central Myanmar: Mesothermal veins in a Mesozoic orogen. *J. Asian Earth Sci.* 23, 321–341. doi:10.1016/S1367-9120(03)00138-X
- Mitchell, A.H.G., Chung, S.-L., Oo, T., Lin, T.-H., Hung, C.-H., 2012. Zircon U–Pb ages in Myanmar: Magmatic–metamorphic events and the closure of a neo-Tethys ocean? *J. Asian Earth Sci.* 56, 1–23. doi:10.1016/j.jseaes.2012.04.019
- Myint, T.A., Than, T.N., Min, A., 2014. Precious and Base Metal Mineralization in Kwinthonze-Nweyon area, Singu and Thabeikkyin Townships, Mandalay Region, Myanmar. *Proc. Sundal. Resour.* 2014 MGEI Annu. Conv. 343–354.
- O'Connor, J.T., 1965. A classification of quartz rich igneous rock based on feldspar ratios. *US Geol. Surv.* 525B, B79–B84.
- Pearce, J.A., Harris, N.B.W., Tindle, A.G., others, 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *J. Petrol.* 25, 956–983.
- Searle, D., Haq, B.T., 1964. The Mogok Belt of Burma and Its Relationship to the Himalayan Orogeny. *Proc. Int. Geol. Congr.* 22, 132–161.
- Simmons, S.F., Christenson, B.W., 1994. Origins of calcite in a boiling geothermal system. *Am. J. Sci.* doi:10.2475/ajs.294.3.361
- Swe, W., 1972. A Strike-slip faulting in central belt of Burma [abstr.]. *Reg. Conf. Geol. SE Asia, Kuala Lumpur. Annex. Geol. Soc. Malaysia Newsl.* 34, 59.
- Thein, M., Win, S., 1969. The metamorphic petrology, structures and mineral resources of the Shantaung-U-Thandawmywet Range,

Kyaukse district. Burma Res. Congr. 3, 487–514.  
Thein, M.L., Myint, O., Kyi, S., Win, H.N., 1990.  
Geology and stratigraphy of the

metamorphosed early Paleozoic rocks of the  
Mogok- Thabeikkyin- Singu- Madaya Areas.  
Yangon.